

# Application of High Speed Parallel Semi-Conductor Fuses To Limit Peak Let- Through Energy

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PACE Engineers Group



Western Mining Electrical Association

17<sup>th</sup> – 18<sup>th</sup> November 2011

# Introduction

- PACE Engineers – Australian Elect/Mech, D&C/EPC Company;
  - QLD
  - NSW
  - New Caledonia
- Working with Caterpillar Global Mining (BE) on Australian Projects – Arc Flash Mitigation
- Specialise in Brownfield, Complex Green/Brown Interfaces or Just Novel Approaches;
- Verticals, Mining & Minerals Processing, Infrastructure. (Black Coal, Nickel, Gold, Lead/Zinc, Bauxite, Alumina, Aluminium Smelting, Ports & Power Generation)



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# Come On Downunder — Crash Course



- We have an acute shortage of fluent English speaking skilled human resources;
- 6 Year Visas, redtape accelerated for US Citizens;
- Were Ozzies not Ausssies;
- We are a Federation of British Colonies;
- Westminster Democracy;
- Liberal Party = Republican Party;
- Labour Party = Democrat Party;
- Greens Party = Idealist;
- We all despise Politics and the Practitioners;
- We hate taxes, but Politian's love them;
- We love sport and must defeat England at all costs;
- Friend = Mate;
- A Shout = Around of Drinks;
- 14hr Flight From LA.



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# Resource Comparison

Item	Australia		USA		World	
	Current	Reserves	Current	Reserves	Current	Reserves
Population	22.3m	2050 – 33m	307m	420m	7b	8.9b
Black Coal	0.460bt	125bt	1.05bt	261bt	5.8bt	669bt
Bauxite	0.069bt	5.5bt	N/A		0.211bt	28bt
Copper	0.87mt	85mt	1.12mt		16.2mt	640mt
Gold	260t	8380t	230t		2510t	51,800t
Iron Ore	0.430bt	47.8bt	0.049bt		2.4bt	191bt
Nickel	0.17mt	21mt	W		1.58mt	75mt
Lead	0.71mt	34.7mt	0.4mt		4.2mt	88mt
Zinc	1.48mt	65.2mt	0.720mt		12mt	260mt
Phosphate Rock	2.13mt	1.27bt	34.6mt		176mt	65bt
Rare Earths	0	24mt	N/A		0.13mt	114mt
Uranium	0.0059mt	1.05mt	0.0021mt		0.054mt	3.5mt



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# Context

- Statutory Acts of Parliament & Regulations holds Operator & Individuals legally accountable (Statutory Manslaughter, Fine & Jail Terms);
- Personnel Safety is about ALARP and the Application of the Hierarchy of Controls Pyramid;
- Electrical Protection Paradigm shift required from a system protection mindset, to human safety mindset;
- IEEE1584 Calculation Method based on validation of time-current behaviour.
- NFPA70E PPE and Boundaries

# Context

- Utilising Parallel Fuses at Low Voltage & High Currents Requires Significant Engineering;
- Be Careful as Power System Analysis Software Results Can Be Miss Leading;
- Parallel High Speed Semi-Conductor Interrupter Modules Have Been In Continuous Service for 3 years at BHPB Mt Arthur Coal NSW and at Wesfarmers Curragh QLD for 7 months providing CAT 0 protection;
- Certified Testing to Validate Calculation and Analysis.

# Why Concentrate on LV

- USA MSHA 1990-2001, 836 arc flash injuries reports.
- Electricians and mechanics made up 59% of the group.
- The most common work activity was electrical maintenance/repair.
- Of the 35% of cases reporting system voltage 84% occurred at 600V or less.



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# Recent History of Fuses

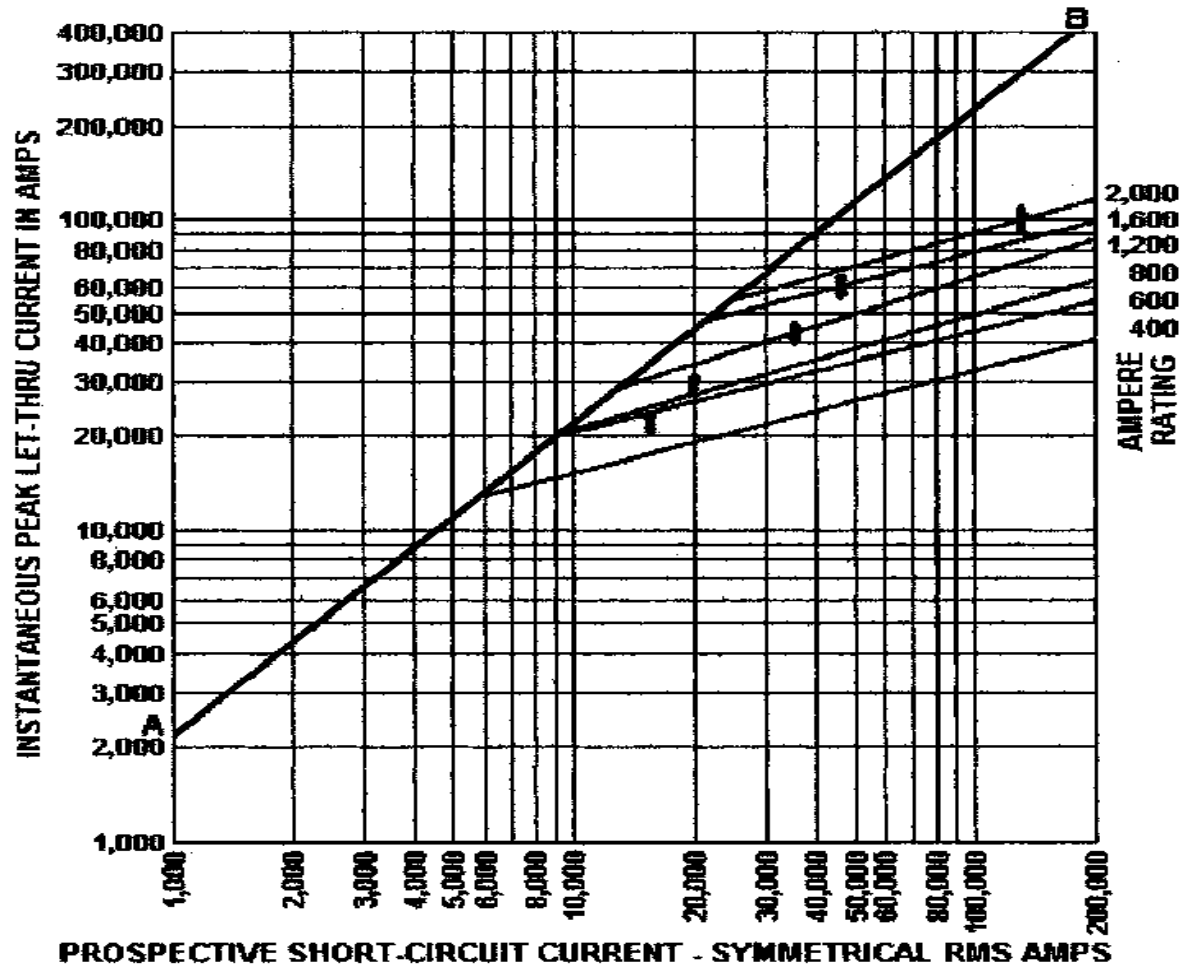
- Modern fuses have significantly evolved since 1940 with semi-conductors usage;
- Fuses characteristics are designed to recognised standards, AS/IEC/UL etc;
- Fuse characteristics are calculated using multivariable calculus and randomly proof tested;
- Fuse manufacturers have sponsored application testing (Cooper Bussmann USA Test Facility 1991USD19M);

# Recent US Arc Flash Research

- 1996 Vincent Saporita (arc-flash benefits)
- 2000 Doughty, Thomas, Macalady, Saporita & Borgwald (relationship between limiting & let-through energy)



# Critical USA Test Results



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# Is Paralleling Common?, YES

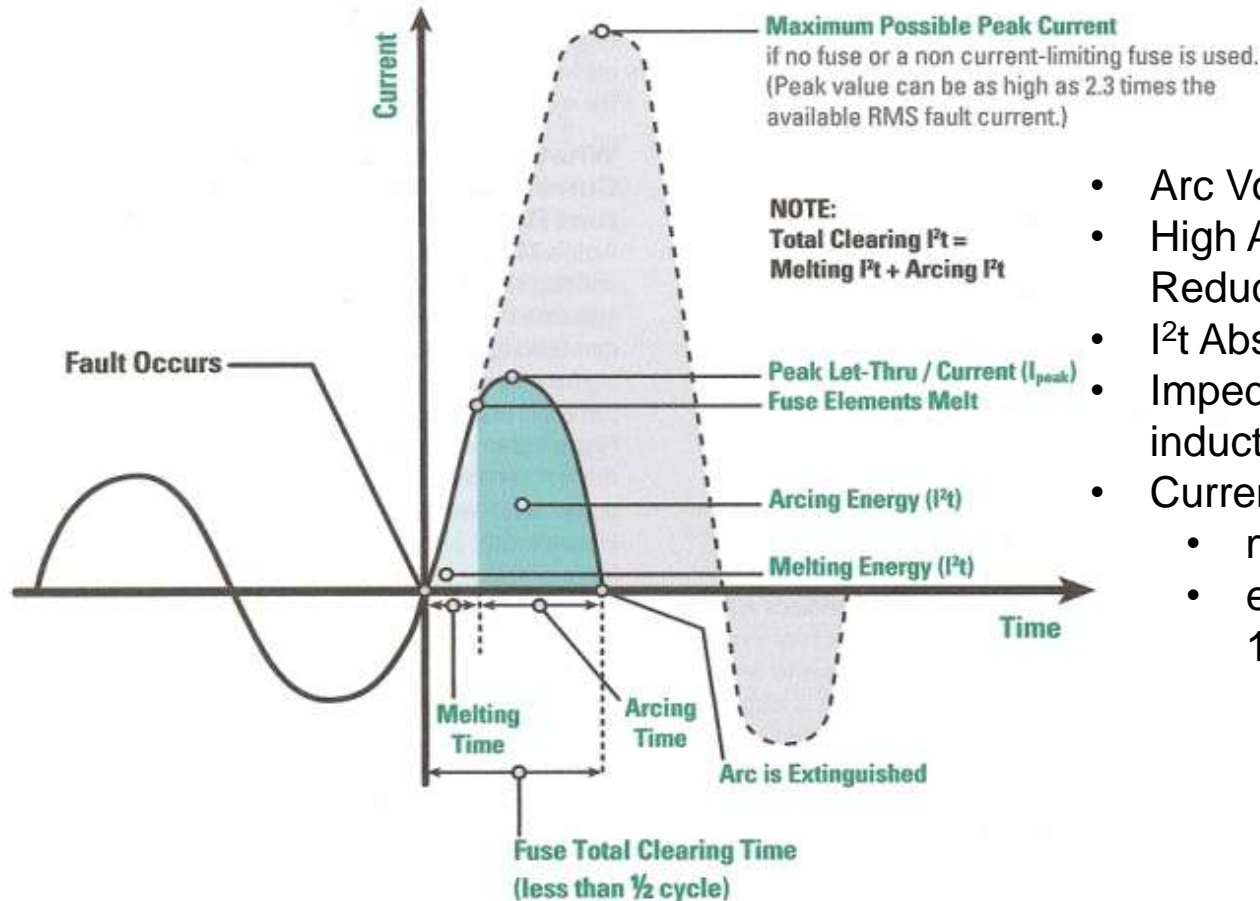
- High current fuses;
- High current applications;
- Minimise stock levels;
- Maximise heat dissipation & minimise losses;
- Semi-conductor industry;
- Is > 2 Common, Well NO, but we engineers understand their behaviour to a degree!;

# Semi-Conductor Fuses

- High speed operation;
- Minimise  $I^2t$  peak let through;
- Small package;
- Elevated temperature & power dissipation;



# Why Do They Work



- Arc Voltage  $\gg$  System Voltage
- High Arc Voltages Limit and Reduce Arcing Current
- $I^2t$  Absorbing during clearing
- Impedance changes from inductive to resistive
- Current flow is (50Hz):
  - minimal within 5ms
  - extinguished within 10ms completely

# Design Considerations

## Operational Reliability

- Fuses the same size
- Connections symmetrical
- Connections tin plated
- Published curves?
- Nominal current rating?
- Coordination?
- Incident energy reduction?
- Package meets Standard

## Package Design

- Busbars
- Insulators
- Enclosure & Mechanical Strength
- Connections
- Weight  $\approx$  1.2 tonnes
- Equipment Mounting
- Performance Monitoring
- Maintenance



# Design Considerations

## Busbar Sizing

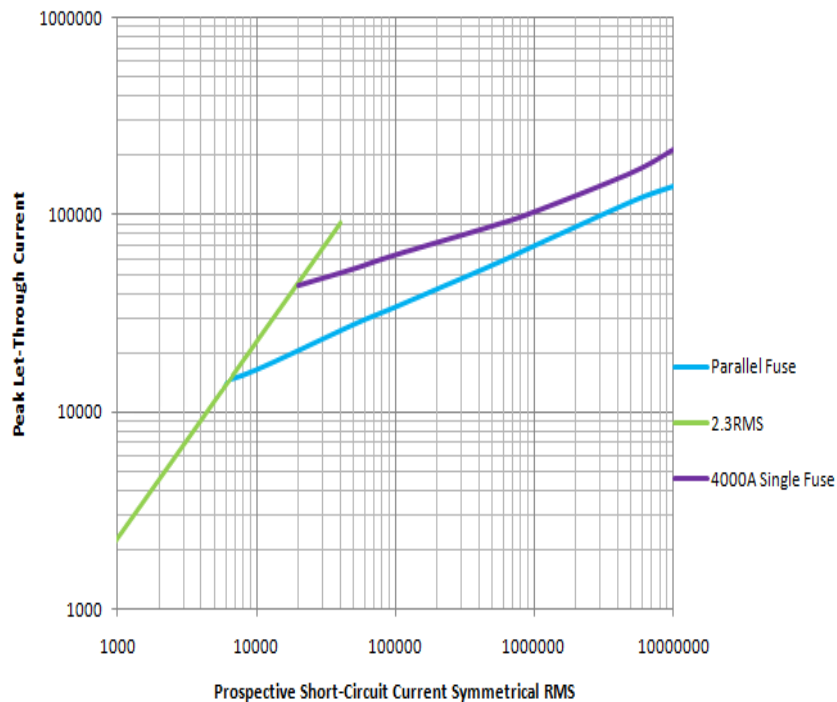
- Skin Effect
- Impedance
- Current Carrying Capacity
- Proximity Effect
- Volt Drop
- Watts Loss
- Short Circuit Withstand
- Weight

## Interrupter Sizing

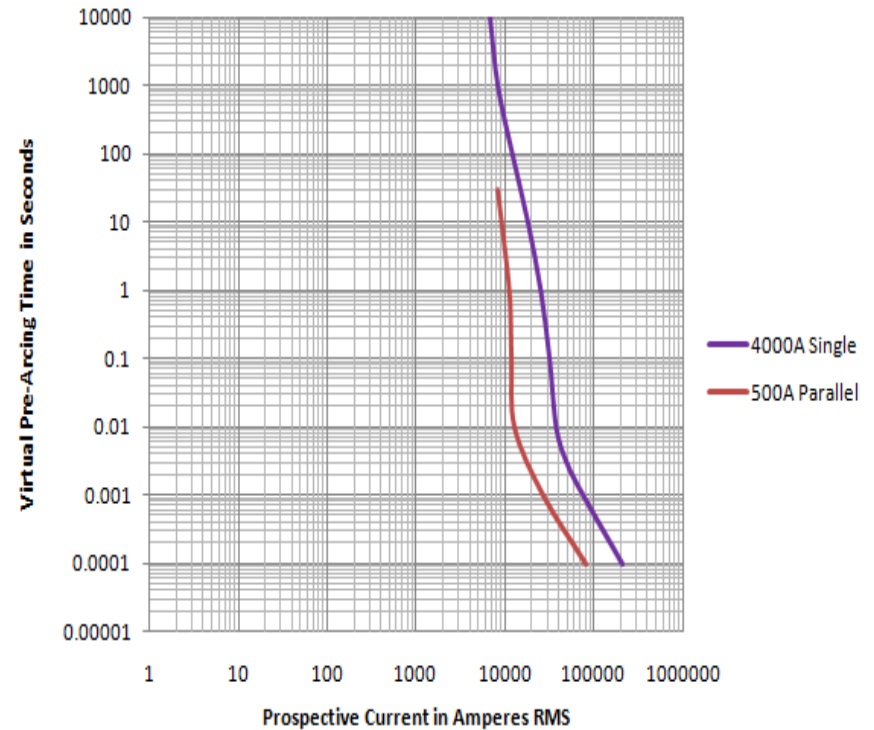
- Operational Voltage  $I^2t$ ,  $\kappa$   
Correction Factor
- Watts Loss Factor  $K_b$
- Cyclic Load Dimensioning
- Current Rating
  - Number in Parallel, (Rules of thumb 2-4 =0.9, 4+ =0.8)
  - Ambient Temperature  $K_t$
  - Cooling Effect  $K_v$
- Peak Let-through ( $n^{2/3}$ )

# Theoretical Characteristics

## Peak Let-Through

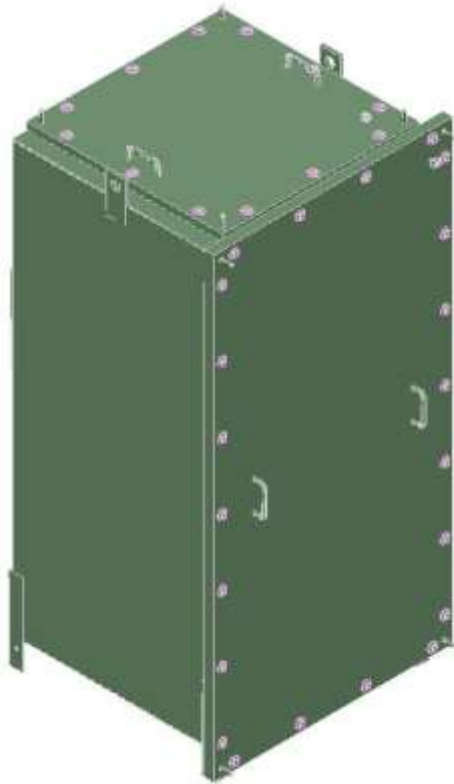


## TCC

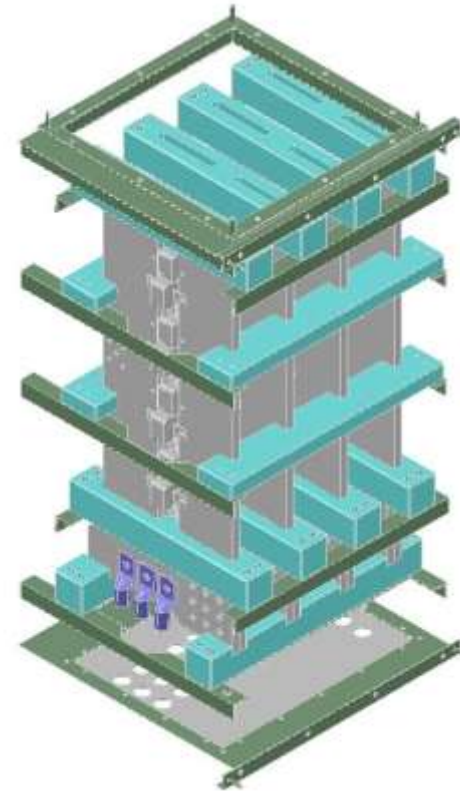


# Result – 3200A Unit, 2009

**Outside**



**Inside**



# Testing of the Theory – 2010

## Test Unit



## Test Procedure

- AS60947.1 Low Voltage Switchgear and Control Gear
- ITACS-TUV/NATA Certified Lab
- Short Circuit Test
- TCC Validation
- Dielectric Tests
- Temperature Rise

# Short Circuit Test Results

Peak Let Through								Time (s)		
Test	R	W	B	Max	STD Dev	Average	% Dev	<i>tp</i>	<i>tc</i>	Max
63000	28300	34300	28300	34300	230.9401	34550	0.668%	0.0037	0.0058	0.0063
63000	27400	34700	27500	34700				0.0039	0.0063	
63000	28300	34700	28400	34700				0.0039	0.0059	
43000	27000	31900	27200	31900		31900		0.0046	0.007	0.0070
20500	24450	26600	14000	26600	513.1601	27167	1.889%	0.0059	0.01	0.0104
20500	23700	27300	15400	27300				0.0062	0.0104	
20500	23700	27600	27600	27600				0.0065	0.0095	
15500	27200	23600	21700	27200	208.1666	27133	0.767%	0.0097	0.0162	0.0162
15500	27300	22700	22700	27300				0.0095	0.0162	
15500	26900	24100	12500	26900				0.0104	0.0127	
11200									5.53	6.0600
11200									5.59	
11200									6.06	
6250								303.6	366	366.00
4500								2400	3000	3000.00

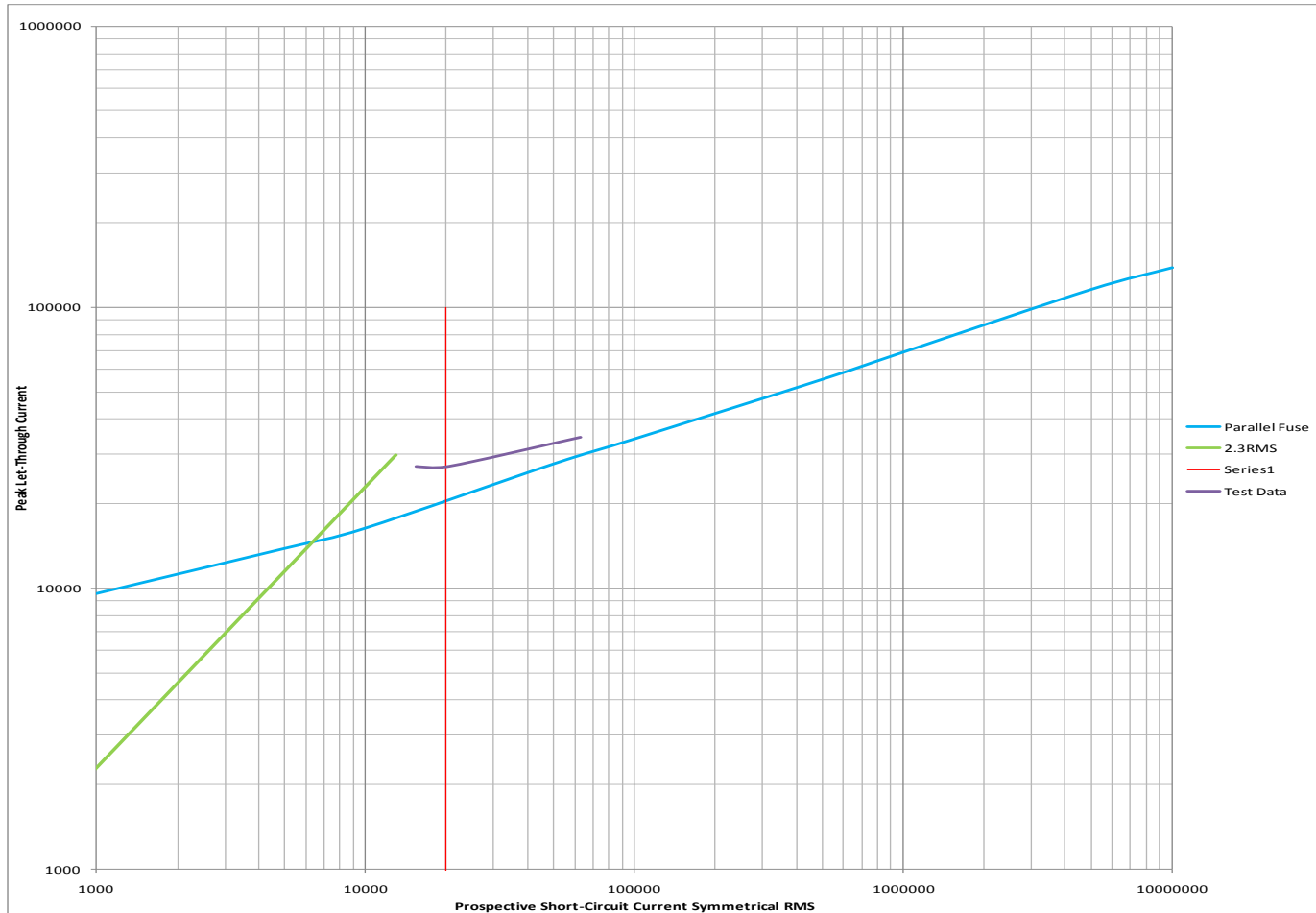


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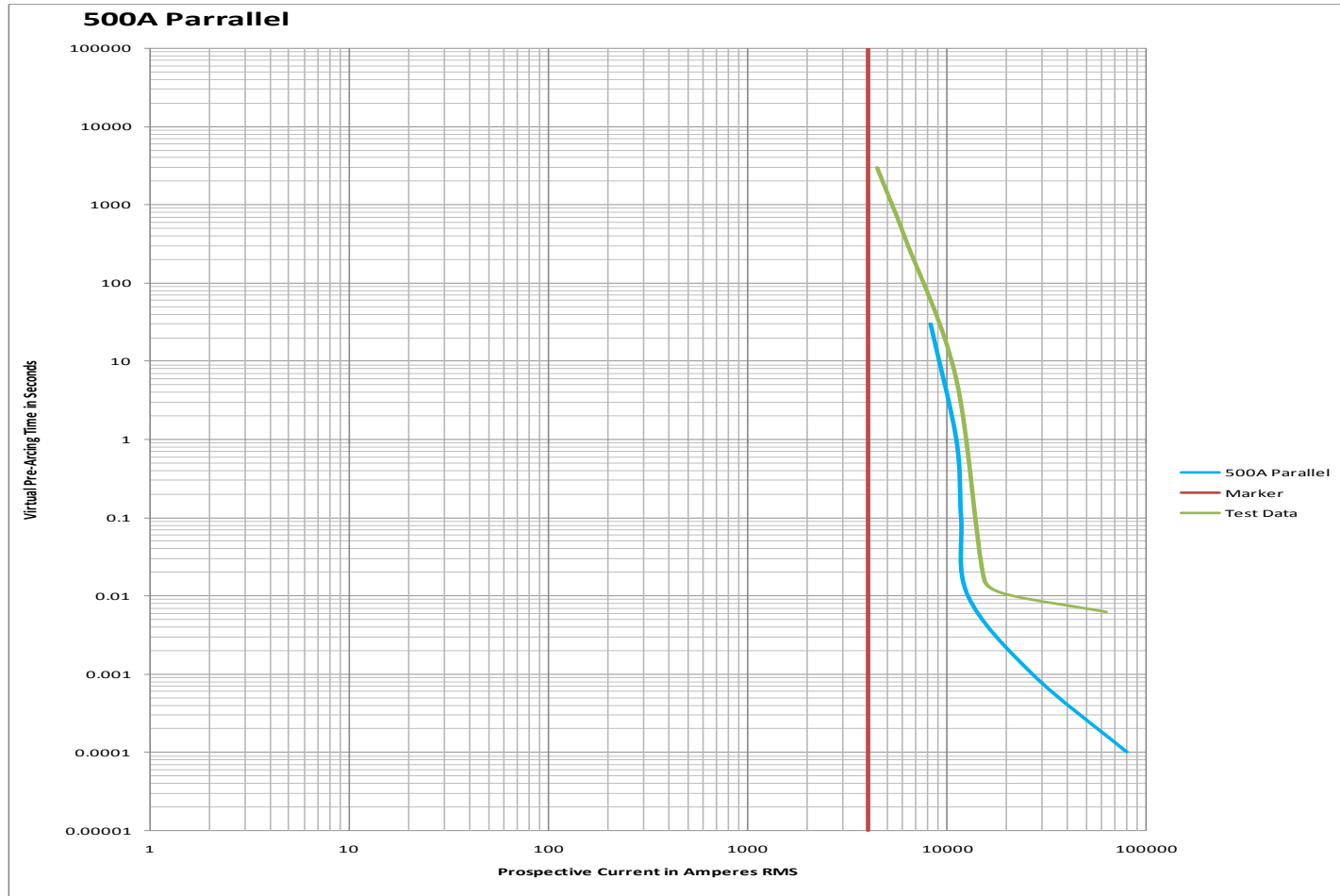


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# Actual Peak Let-Through



# Actual TCC





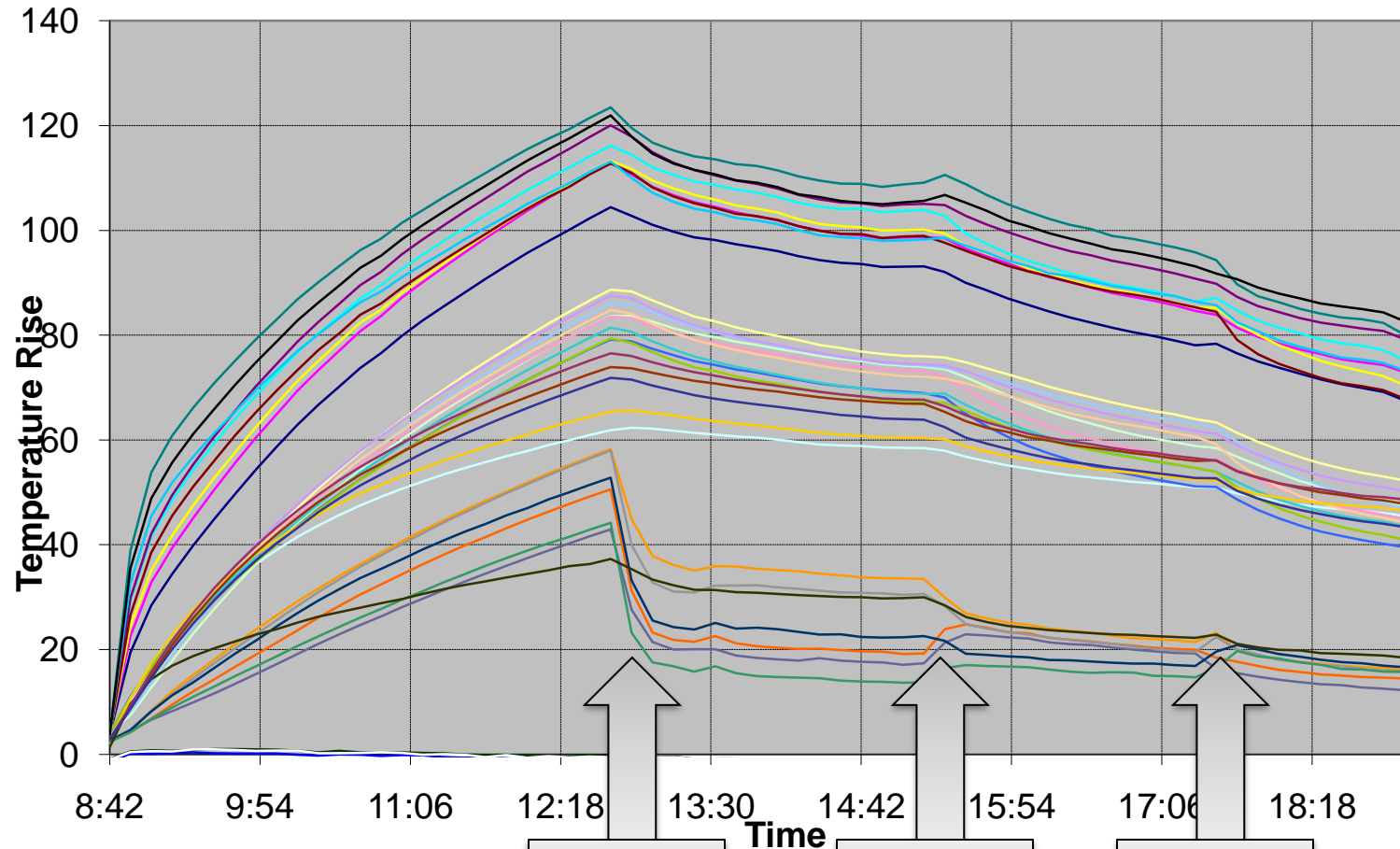


# Temp Rise – Bugger



- Natural Ventilation
- Forced Ventilation
  - 1 Fan
  - 2 Fans

# Temp Rise – There's Hope



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# Testing Improves Knowledge

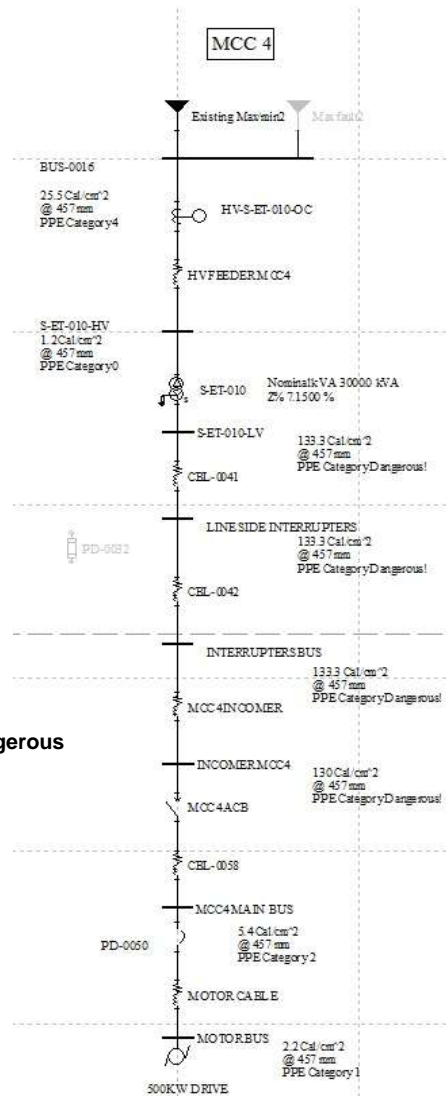
- Confirms Suspicion that Premature Interrupter Fail on two heavily loaded units at MAC is due to heat degradation
- System Impedance Characteristics
- Watts Loss/Heat Generation
- Busbar Connections;
- Cooling Options Needed
  - Heat Tube (IP65)
  - Forced Ventilation (IP55)

# BHPBilliton – Mt Arthur (MAC)



# MAC System Modelling

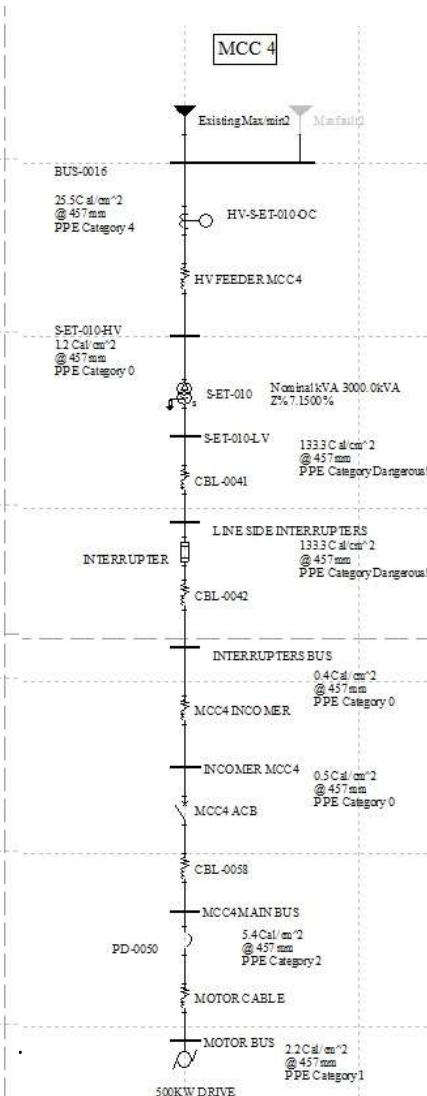
## Without Parallel Fuse



**MCC Incomer**  
130 Cal/cm<sup>2</sup>  
PPE CAT Dangerous

**MCC Bus**  
5.4 Cal/cm<sup>2</sup>  
PPE CAT 2

## Parallel Fuse

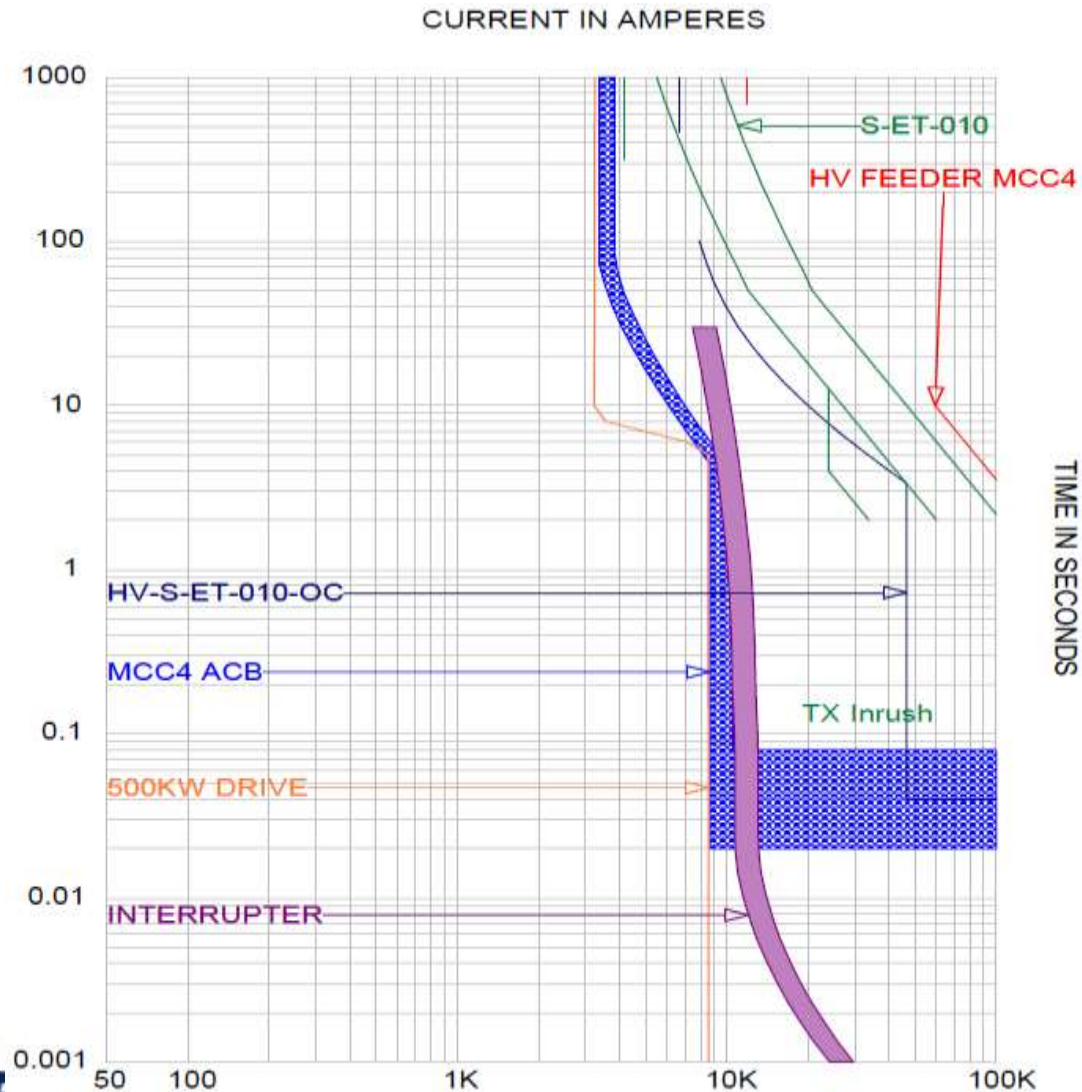


**MCC Incomer**  
130 Cal/cm<sup>2</sup>  
PPE CAT 0

**MCC Bus**  
5.4 Cal/cm<sup>2</sup>  
PPE CAT 0



# MAC Coordination



# BHPBilliton – Mt Arthur (MAC)



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# Wesfarmers – Curragh



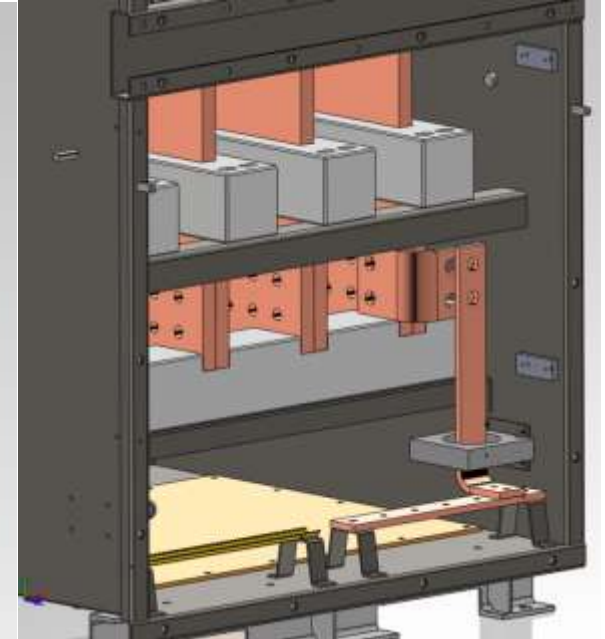
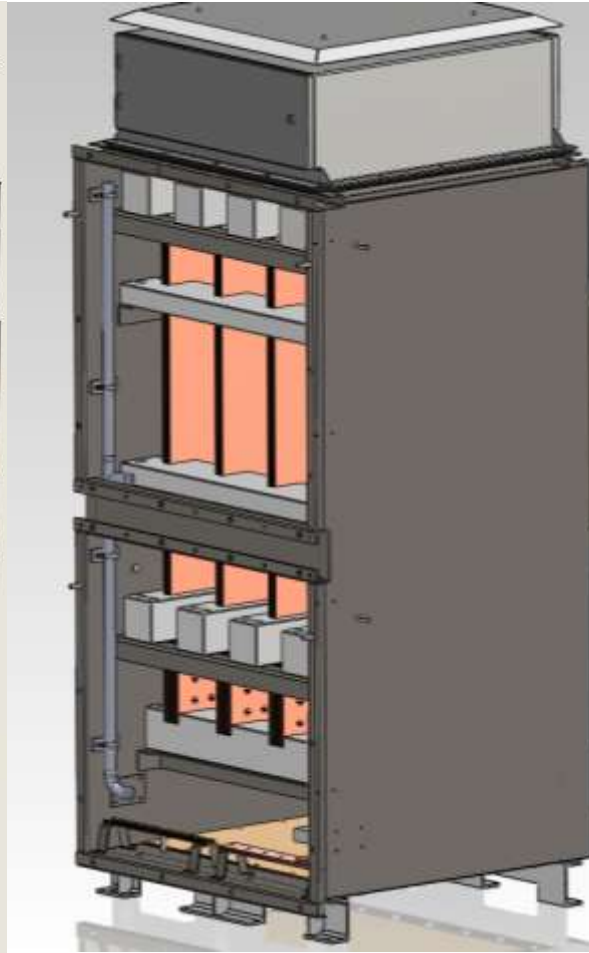
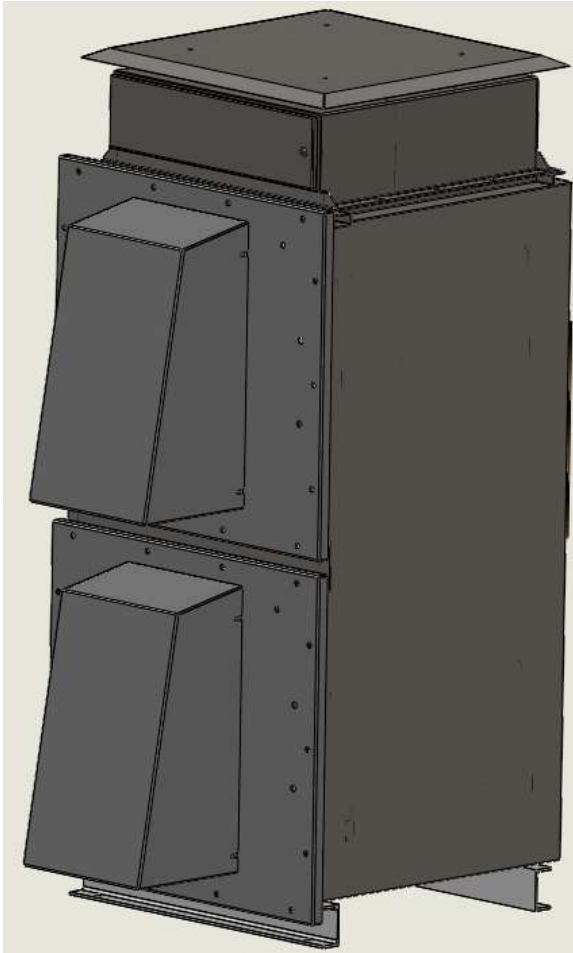
# Wesfarmers – Curragh



# Caterpillar (Bucyrus) Electric Shovels



# The Development Future



- AS60947 Heat Rise Tests (Aus)
- Additional TCC validation (US)
- UL Supervised IEEE1854 Arc-box Testing (US)



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# BHPB Mt Arthur Coal - Installs

- 9 x 3MVA Restricted Load 3200A Units Operating @ Between 2500 & 3150A
- 1 x 1.5MVA Full Load Unit
- 2 x 2MVA Full Load Units
- 3 x 2MVA Commercialised Full Load Units (*Under Construction*)
- 30kA 1 Sec System MCC Rating
- Cat 0 Arc Flash at MCC
- Cooling to fitted to development units to remove load restrictions



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# Wesfarmers Curragh - Installs

- Caterpillar (Bucyrus) adopt technology on New Electrical Shovel CAT 0 415V MCC;
- Bucket Wheel Reclaimer PCR MCC CAT 0.

# Questions ?

